AN UPDATE ON OPERATION OF THE MAMMOTH GEOTHERMAL POWER PLANTS

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ABSTRACT

The world's first modular air-cooled binary plant was designed to produce a year-round average of 7,000 kW net. Firm power was first produced in February, 1985. This privately financed plant has met design objectives to the satisfaction of the Mammoth-Pacific Joint Venture.

Reservoir performance has been excellent. There is no evidence of a decline in productivity and injection well pressures have been lower than anticipated. Downhole pumps have been in operation in excess of one year without servicing.

The equipment in the plant has been operating well. Early problems due to resonant frequencies in the turbine have been solved. Fouling of the brine-to-isobutane heat exchangers has been less than expected and the heat exchangers have not yet required cleaning. Isobutane pumps and the air coolers have performed in accordance with expectations.

Plans are underway to expand the geothermal development at Mammoth, employing the Magmamax process and the same environmentally benign design concepts.

ACKNOWLEDGEMENTS

It is appropriate to acknowledge the assistance, support and effort of the many individuals who have made this pioneering effort a success. The project is another successful demonstration of the Magmamax process, invented by B.C. McCabe, Chairman of the Board of Magma Energy, Inc. The well testing work carried out by Mr. McCabe and his associates at the site in the early 60's showed that free flowing wells would release carbon dioxide and cause heavy scaling in the well bores. This finding led to the invention of the Magmamax process, which prevents scaling in the well or in the plant by down-hole pumping, thereby maintaining the reservoir fluid at all times in the liquid phase.

Magma's binary plant at East Mesa, California and the 50 MW Heber binary plant both employ this principle.

Other supporters of the project include Mr. Richard D. Farman, President of Pacific Geothermal Co.; Mr. Milton R. Tanner, Executive Vice President of Pacific Geothermal Co.; Mr. Andy Hoch, President of Magma Power Co.; Mr. George Crane of Edison; and The Ben Holt Co.'s Project Manager, Frederick Torn.

BACKGROUND

The Mammoth Geothermal Project is located within the Long Valley Known Geothermal Resources Area (KGRA) on the eastern slope of the Sierra Nevada mountain range of California some 300 miles north of Los Angeles. Three miles west of the plant is the village of Mammoth Lakes, a well-known winter and summer resort.

The plant is owned by Mammoth-Pacific (M-P), a joint venture of Pacific

Geothermal Company (a subsidiary of Pacific Lighting Corporation of Los Angeles) and Mammoth Binary Power Company. The general partner of Mammoth Binary Power Company is Holt Geothermal Company, an affiliate of The Ben Holt Co. based in Pasadena, California.

Magma Energy, Inc. has leased the plant site to M-P and has licensed M-P to use its patented Magmamax process.

Design and construction was handled by The Ben Holt Co., who also through the Mammoth Binary Power Co. operates the plant. Field construction of the power plants was minimized by the use of modular design. Two identical units were built, side by side, with common utilities and common spare equipment. Wherever possible, equipment was skid-mounted and/or shop fabricated to minimize field costs. All of the system components are commercially available.

Design and operation of the plant takes advantage of the low ambient temperatures at the plant site. The plant is at an elevation of 7300 feet with an annual average dry bulb temperature of approximately 40°F. Condensation of the working fluid uses floating cooling. That is, the condensing temperature is allowed to vary with changes in the inlet air temperature. Power production during the summer is lower than average but the high power production during the rest of the year makes up for the low summer production.

The geothermal brine at Casa Diablo has a dissolved solids content of about 1500 ppm and is non-corrosive. As a result, the piping and power plant have been built with carbon steel as the primary material of construction.

THE RESERVOIR

Eight geothermal wells were drilled on Magma's property and flow tested in the early sixties. This early work demonstrated the existence of a reservoir of hot water at shallow depths (400 to 800 ft). Reservoir temperatures averaged about 330°F and total dissolved solids were about 1500 ppm.

DESIGN CRITERIA

The following criteria were the key elements in deciding upon the design: The facility must be environmentally acceptable since it is surrounded with National Forest land in an area possessing great scenic and recreational value.

In order to minimize construction costs in a remote area, the facility should employ modular construction techniques to the maximum extent possible.

In order to qualify as a base load facility, it should be designed for high availability and reliability.

These considerations led to the choice of a simple binary cycle plant employing 100% air cooling. The geothermal fluid is maintained in a liquid state throughout and 100% of the fluid is reinjected. Moreover, no cooling water is required in an area where fresh water is at a premium. Thus the plant is a pollution free installation.

Air cooling also permits taking advantage of the cold air as a cooling medium particularly in the wintertime, thereby increasing thermal efficiency and power output by reducing condensing pressures in the season when power is most needed.

Low construction costs and high reliability are ensured by providing twin units, each having a capacity of 3.5 MWe, calculated on a yearly basis.

SYSTEM DESCRIPTION

Isobutane is the working fluid in a Rankine cycle. Vaporization is sub-critical though near the critical point. Condensation of the turbine exhaust is in air coolers.

The design basis of each module is as follows:

1. The Brine:
   a. Temperature in: 330°F
   b. Temperature out: 150°F to 190°F depending on ambient temperature
   c. Flow rate: 640,000 lbs/hr
2. The Working Fluid:
   a. Composition: Isobutane
   b. Turbine inlet: 500 psia, 280°F
   c. Condensing temperature: 70°F to 120°F
      depending on ambient air temperature
   d. Cooling: 100% air
   e. Flow rate: 580,000 lbs/hr

Operation using the floating mode concept results in varying power outputs throughout the year. Monthly average production is near 8 MWe during the winter with low air temperatures and low turbine back pressures. Power during the summer is about 6 MWe due to higher turbine back pressures and off design operation. The total annual power output is higher using this floating mode concept than if a single high air temperature was chosen as the design point for year-round operation.

The nameplate generator capacity for each unit is 5,000 kW. Parasitic load for each unit is 1,000 kW. Thus the design net power for sale is 4,000 kW. However, year-round output is estimated to be 3,500 kW.

Field pumping requires about 300 kW for each unit.

The geothermal brine is pumped from the production wells and through the heat exchangers using vertical line-shaft turbine pumps. Cooled brine leaving the heat exchangers is pressurized for reinjection by centrifugal pumps at the plant site.

CONSTRUCTION HISTORY

Groundbreaking for the facility started in September of 1983 and the power plant was mechanically complete and ready for operation in October of 1984. Prior to the onset of severe winter weather in 1983, foundations were poured, structural steel supports for the air coolers were installed and the office, control room and warehouse building were built. Construction resumed in April of 1984.

Four production wells and two injection wells were drilled in the fall and winter months. Testing was limited to short term open flow tests into Baker tanks.

The production pumps were installed in the spring and most of the field piping completed. A program of production and injection well testing was undertaken in the summer and early fall.

OPERATING HISTORY

The operating history of the plant and field as of June 1, 1986 may be summarized as follows:

WELLS:

The four original production wells (MBP-1, 2, 4 and 5) were drilled to a depth of 650'. Casing was set and cemented at 250' and a slotted liner (9-5/8") set at depth. Pumps were set at 600'.

One injection well (IW-2) was drilled to a depth of 1,800 feet. The injection interval was 1,300 to 1,800 feet. The second injection well was a converted well drilled in 1979 by Union Oil Company. It was plugged at 1,900 feet. The 7" liner was slotted from 1100 to 1900 feet.

During early operation, three of the wells (MBP-2, 4 and 5) developed communication to the surface indicating a failure of the casing cement. The surface eruptions adjacent to the wells were sufficiently serious to require reworking MBP-4 and MBP-5 and abandonment of MBP-2. The reworks were successful and involved removing the casing and liner, resetting and cementing the casing to 400 feet.

Late in 1984 a new well, MBP-3, was drilled as well as a third injection well (IW-1). At the present time, three of the wells (MBP- 1, 3 & 4) are sufficient to supply the plant (about 3,400 gpm at 340°F) and appear to be pump limited.

Very little drawdown occurs on each well and wellhead temperatures have remained constant.

The production pumps have given excellent service and show no indication of reduced performance as a result of corrosion or erosion.

All three injection wells are in service.

THE PLANT: The first unit (Unit 100) was turned over to operations in October. In November chemical cleaning of the isobutane circuit was completed and isobutane loaded. Circulation was established and the first power was sent to the grid in late November, 1984. Firm operation from the first unit was established in February 1985. The second unit first delivered power to the grid in March of 1985.

Numerous startup problems have been encountered and solved, not the least of which was the necessity of starting up during the winter. The current status of the power plant equipment is as follows:

THE ISOBUTANE PUMPS: These are vertical multi-stage centrifugals that have operated according to specifications.

THE BRINE-ISOBUTANE HEAT EXCHANGERS: Each unit is equipped with six fixed tube sheet single pass heat exchangers. No scaling or corrosion on either shell or tube-side has been observed. Excess surface was provided to allow for scale buildup. So far, no measurable decreases in overall transfer rates have been observed.

During the winter we froze and broke a few tubes during startup. They were plugged off. No further leakage has been observed.

THE AIR COOLERS: Each unit contains eleven air cooler sections in parallel. Each section is equipped with three fans. The air coolers have performed in accordance with expectations. Maldistribution of isobutane to the coolers does not appear to be a problem.

TURBINE-GENERATORS: The turbine in each unit is a radial-inflow type rotating at 11,000 RPM and driving at 5,000 kW synchronous generator through a

gear reduction unit. These three units are mounted on a single skid. A second skid contains the lube oil storage, degassing and pumping equipment.

Normal start-up problems have been encountered, principally relating to the control sytem components. A major problem has been the unexpected resonance failure of several turbine wheels. This problem appears to have been satisfactorily remedied by the vendor.

Problems were also encountered in the gear reducer. The problems have been solved by limiting shaft power and by changing the lubricating oil temperature.

STAFFING

We employ two operators per shift around the clock. Three permanent maintenance technicians are employed on days. A plant manager, a plant superintendent and a secretary complete the staff. Accounts payable, payroll and technical services are provided by The Ben Holt Co.'s Pasadena office.

ECONOMICS

The power plants were constructed within the original budget estimate of $10,000,000, equivalent at the design output of 8,000 kW to a cost of $1,250/kW.

The field budget of $2,500,000 was exceeded by the need for remedial work and drilling additional wells.

FUTURE PLANS

M-P has entered into a power sales agreement with Edison for an additional 20,000 kW (gross). Preliminary work is under way.